B-4.1.2   Contemporary Geologic Processes

Within the ESRP region, which includes the Yellowstone Plateau and the northern Basin and Range Province that flanks the plain, several geologic processes may affect the choice of remedial alternatives for the WAG 10 and WAG 6 sites: subsidence of the plain itself, faulting in the northern Basin and Range Province, and volcanism on the plain. These processes have governed the dynamics of geology in the ESRP for the last several million years.

Subsidence at a rate of about 0.5 mm (0.02 in.) per year is occurring on the ESRP (Smith et al. 1994) and continues to maintain the low elevation of the plain relative to the surrounding mountains. The subsidence, coupled with the closed basin watershed of much of the northwestern part of the plain, ensures that net accumulation of sediments and lavas will continue in this region. Faulting is an ongoing response to extensional deformation of the crust in the Great Basin and the northern Basin and Range Province of the western United States. The ESRP, because of its volcanic nature, responds to the extension by intrusion of basaltic dikes, a process that produces only minor seismic activity compared to the large earthquakes associated with the faulting in the adjacent Basin and Range Province. The region extends at a rate of 2 to 3 cm (0.8 to 1.2 in.) per year (Rodgers, Hackett, and Ore 1990). The general northeast-southwest extension direction causes both the Basin and Range faults and the dikes beneath the ESRP to trend in a northwestward to northward direction (Figures B-6 and B-7). The differing mechanisms of accommodation of the extension account for the observed high seismic activity in the Basin and Range province and the low seismic activity within and near the ESRP.

The Lost River and Lemhi ranges (Figure B-7) are classic examples of the block faulting process. They are more than 100 km (62 mi) long and 20 to 30 km (12 to 18 mi) wide, and are separated from each other by long narrow valleys (or basins) that also are about 20 km (12 mi) wide. Each of the ranges is bounded on its southwest side by a normal fault along which episodic faulting (and earthquakes) allows the basin to subside and the mountain range to move upward in response to the persistent extension of the region. The Lost River and the Lemhi faults, the closest major faults to the INEEL, contribute a major part of the seismic hazard to facilities. The seismic hazard potential is discussed in more detail in Section 2.4.3.

Basaltic volcanism is a continuing phenomenon on the ESRP, most recently occurring about 2,000 years ago along the Great Rift, 30 km (18 mi) south of the INEEL. Since passage of the Yellowstone hot spot from the plain, residual heat in the upper mantle continues to cause local melting deep beneath the surface. At times, batches of basaltic magma accumulate in volumes large enough to allow upward movement in dike like conduits toward the surface. Though the age of the youngest lava flow on the surface within the INEEL is approximately 10,000 years, flows as recent as 2,000 years have been identified nearby. Because the dikes respond to the same extensional stress field as the normal faults outside the plain, they are oriented into a northwesterly trend. The orientation allows them to do minimal work in pushing the walls apart because the crust is extending in a northeast direction. The intrusion of northwesterly trending dikes in the volcanic rift zones accommodates the extension of the plain and allows it to keep pace with the surrounding Basin and Range extension without normal faulting and large earthquakes (Parsons and Thompson 1991; Parsons, Thompson, and Smith 1997). Batches of magma tend to rise in preferred areas, producing northwesterly trending volcanic rift zones such as the Great Rift and the Arco volcanic rift zones (Figure B-7) (Kuntz, Covington, and Schorr 1992; Hackett and Smith 1992). In addition, several eruptions tend to be clustered in time, with long periods of quiescence between clusters. For example, in the Great Rift volcanic rift zone, eight eruptions have occurred within the past 15,000 years, but the basalts onto which the young lavas erupted are several hundred thousand years old. Relatively recent volcanism also has occurred at the southern end of the Arco volcanic rift zone. The Cerro Grande, North Robbers, and South Robbers flows near Big Southern Butte are a little more than 10,000 years old, and just outside the southeast corner of the INEEL, the Hells Half Acre lava

field is about 5,000 years old (Figure B-7). In contrast to the northeastward migration of older silicic volcanism related to passage of the Yellowstone hot spot, there appears to be no pattern of spatial migration of basaltic centers of volcanic activity with time on the plain. Eastern Snake River Plain basaltic volcanism is characterized by low-volume, effusive eruptions in which lava exudes from fissures or small shield volcanoes. Historically, the gentle slopes on the plain surface and the relatively low effusion rates of lava have limited the advance of lava across the landscape to slow rates of only a few meters per hour or less. Volcanic hazards to INEEL facilities are discussed in Section B.4.3.

B-4.1.3   Snake River Plain Aquifer

The geologic events that gave rise to the ESRP also produced the Snake River Plain Aquifer (SRPA). The SRPA is a world-class aquifer in terms of the volume and the quality of groundwater, and is also classified as a sole source aquifer by the U.S. Environmental Protection Agency (DOE-ID 1996). As indicated below, almost all of the important steps in creation of the aquifer resulted from the effects of the Yellowstone hot spot.

- First, the elevation of the land surface above the hot spot produced a large highland, which includes the Yellowstone Plateau and perhaps contributes to the high elevation of a large part of the Northern Rocky Mountains in Wyoming, Montana, and Idaho (Figure B-6). This highland effectively traps moisture from Pacific winter storm systems and brings about accumulation of large snow packs in the region surrounding the ESRP, especially in surrounding mountains and the Yellowstone Plateau. Melting of snow packs in springtime is a major recharge source for the aquifer.

- Second, the subsidence of the ESRP following movement off of the hot spot affected not only the plain itself, but a large area of the mountainous Basin and Range province to the northwest and southeast of the plain. This means that the plain receives drainage from the northern ends of the mountains southeast of the plain, the southern ends of the mountains northwest of the plain, and the entire Teton Range including the Jackson Hole area.

- Third, the basin-fill materials in the ESRP are ideally suited to host the voluminous groundwater contributed by the surrounding mountains. A thick sequence of very porous and permeable rocks has accumulated in the plain basin. The processes of basaltic volcanism in the wake of the Yellowstone hot spot are responsible for most of the porosity and permeability of the rocks. The melting of mostly small batches of basaltic magma caused by residual heat beneath the plain ensured that lava flows were relatively thin, about 6 to 7 m (20 to 23 ft) on average. The mechanism of emplacement of the lava flows on the surface, involving lava flowage within a solidified crust, produced thick, porous, and permeable rubble zones at the base of each lava flow. The trapping of contained gases as the lava solidified produced abundant open vesicles in the basalts. The contraction of the lavas as they cooled to ambient temperatures produced fracture networks within each lava flow. The deposition of sandy and gravelly sedimentary materials between some lava flows enhanced the water-holding and -carrying capacity of the matrix, whereas the deposition of silty and clayey materials produced impermeable zones.

- Fourth, the natural setting of most of the watershed, the lack of large urban or industrial areas in the ESRP, and the absence of soluble materials in the geologic units encountered by aquifer waters all contribute to the purity of the Snake River Plain Aquifer. Historically, the major threats to the aquifer have been agricultural activities such as pumping for irrigation and fertilization, pesticide use, irrigation return practices, and some INEEL waste disposal

practices such as injection wells and percolation ponds. As urbanization increases in areas like Idaho Falls and Pocatello, new threats to the aquifer may develop.

B-4.2 INEEL Geology

The distribution of geologic materials at the surface and in the subsurface is an important consideration for the remedial action selection process for several reasons. First, aquifer protection will be greatest in areas with large thicknesses of fine-grained, low-permeability, high-porosity sediments in the vadose zone. These types of sediments may minimize water and contaminant transport by slowing the movement of water and sorbing contaminants on mineral grain surfaces. Some areas on the INEEL, such as the area east of the Big Lost River in the central portion of the INEEL, contain sediment for the entire interval from the surface to the underlying water table. Second, the seismic hazard is affected by the interlayered basalt and sediment, and by the thickness of surficial sediment above bedrock. The stratigraphy is highly variable across the INEEL. Figure B-8 (Anderson 1991) illustrates the basalt and sediment sequences for a single cross section from the New Production Reactor (NPR) test site, through the Idaho Nuclear Technology and Engineering Center (INTEC), CFA, and Experimental Breeder Reactor (EBR)-I areas, to the Radioactive Waste Management Complex (RWMC). This illustration, generated by simple linear interpolation of media descriptions taken from six cores, clearly demonstrates the complexity of the subsurface.

Major geologic units in the INEEL include basalt lava flows, fluvial sediments along the Big Lost River, lacustrine (lake) sediments in the northern and northeastern parts of the INEEL, sediments deposited in playas (ephemeral lakes that have water only during parts of the year or once in several years), and eolian sediments (windblown silt and sand) (Figure B-9) (Kuntz, Covington, and Schorr 1992; Kuntz et al. 1994; Hackett and Smith 1992). Basalt lava flows, ranging in age from more than a million years to less than 15,000 years, cover most of the southern two thirds of the Site. They generally lie in topographically high areas that stand above the Big Lost River floodplain. The volcanic vents for these lava flows occur in the northwest trending volcanic rift zones and along the northeast trending axial volcanic zone (Figure B-9).

Several different sedimentary environments exist on the INEEL. Strong subsidence in the north-central part of the Site, in a broad area that includes the Big Lost River and Little Lost River Sinks and Test Area North (TAN), has produced a perpetual low closed basin, which contained a large lake (Lake Terreton) or perhaps several lakes during Pleistocene glacial periods more than 10,000 years ago. Clay-rich and silty lacustrine sediments have accumulated to thicknesses of about 100 m (330 ft) in some places and make up all or most of the vadose zone. Such areas of thick sediment offer very good aquifer protection because of the extremely low permeability of the materials and the ability of clay minerals to inhibit migration of potential contaminants.

In a broad northerly trending band along the course of the Big Lost River, the major sedimentary process has been deposition of gravelly and sandy alluvium along the floodplain of the river. The thickness of this alluvium ranges from less than a meter to approximately 18 m (a few feet to 60 ft) along the reach of the river from CFA to the Naval Reactor Facility (NRF). North of NRF, a transition zone exists in which the sandy and gravelly alluvium grades into and interfingers with the clay-rich and silty lake sediments to the north. Some of the interbeds at depth beneath the alluvial floodplain probably also are composed of alluvial materials similar to those at the surface, but few drill holes have produced core samples to verify this speculation. In terms of aquifer protection, however, this area is less favorable than the northern part of the INEEL where the thick lake sediments occur.
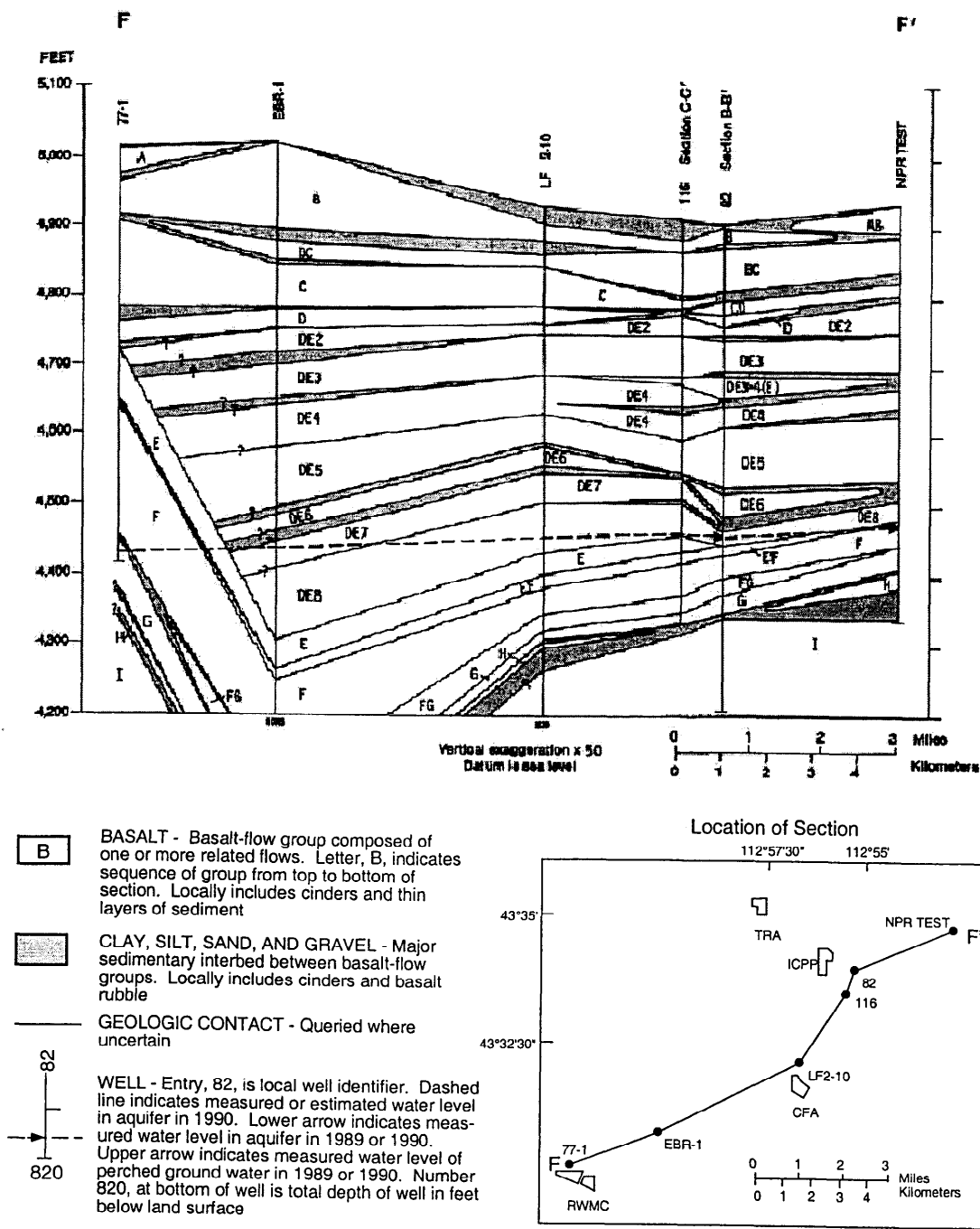
Figure B-8. Geologic section F-F' through the RWMC, the INTEC, and the NPR site (Anderson 1991).

Low areas with relatively large local watersheds commonly are sites of frequent collection of melt water in springtime and storm water in summer. The runoff from these local watersheds commonly deposits clay and silt in the low spots during times of water ponding to produce playas. Subsequent soil-forming processes and evaporation of ponded water often add calcium carbonate deposits (caliche) to the material. Important playas include the RWMC spreading areas, Rye Grass Flats just southeast of CFA, a small playa near the Power Burst Facility (PBF), the Big Lost River and Little Lost River Sinks, the TAN area, and a small area near the eastern boundary of the INEEL (Kuntz et al. 1994).

Eolian (windblown) deposits composed mostly of silt (loess) and fine sand occur throughout the INEEL and the entire ESRP (Scott 1982; Kuntz et al. 1994). Within the area of basalt lava flows, some areas are covered by loess accumulations up to several meters thick, especially on the leeward sides of hills and ridges. These deposits tend to subdue the rugged, irregular topography of the lava flow surfaces and furnish a suitable medium for vegetation growth. Figures B-10 and B-11 illustrate the surface media and topography of the INEEL.

Because loess deposition has been an active process throughout the subsidence history of the ESRP, most of the thin interbeds within the basalt sequence are composed of loess. This is especially true of the highlands along the Axial Volcanic Zone and along some volcanic rift zones where streams or lakes have never been present. Eolian deposits manifested as linear sand dunes covering parts of the older lake bed deposits also are prominent in the north-central portions of the INEEL.

B-4.3 Seismology and Volcanism

INEEL is located on the Eastern Snake River Plain (ESRP), a broad low-relief basin floored with basalt lava flows and sediments (see Figure B-7) (Hackett and Smith 1992). The ESRP is about 80 to 100 km wide and over 560 km long. It transects and sharply contrasts with the adjacent mountainous country. Surface elevations on the Snake River Plain decrease continually and gradually from about 2000 meters above sea level near Yellowstone to about 650 meters near the Idaho-Oregon border (Malde 1991). Peaks of mountains surrounding the Plain range up to 3,700 meters in elevation, producing a maximum elevation contrast of about 2,300 meters.

The ESRP is a volcanic province that developed in response to the passage of the North American tectonic plate across the Yellowstone hot spot, a rising plume of anomalously hot material in the earth's mantle (Armstrong et al. 1975; Pierce and Morgan 1992). The hot spot now resides beneath the Yellowstone Plateau, but the ESRP passed over it several million years ago. While the hot spot was beneath the ESRP a large rhyolite volcanic field was formed, similar to the volcanic rocks of the Yellowstone Plateau today (Hackett and Morgan 1988). The calderas that erupted to produce the Heise volcanic field now lie beneath the ESRP, having been buried by later basaltic volcanism and sedimentation. When the ESRP moved off the hot spot about 4 million years ago, the land subsided, forming an elongate basin, which has been filled with basalt lava flows and sediments carried by streams and winds from surrounding mountains (Hackett and Smith 1992). Basalts exposed at the surface on the INEEL range in age from over 1 million years to about 12,000 years. Basalts a few miles away from the INEEL at Hells Half Acre lava field are about 5,000 years old and at Craters of the Moon as young as 2,000 years (Kuntz et al. 1994).

Extensional faulting started about 17 million years ago in the Basin and Range Province surrounding the ESRP and continues to today (Pierce and Morgan 1992). The Lost River range, the Lemhi range, and the Beaverhead range, are each bounded along their western sides by large active faults that are capable of generating earthquakes of magnitude 7 or slightly greater. The south ends of these faults lie very close to the western and northern boundaries of the INEEL and are the major sources of seismic hazards for INEEL facilities.
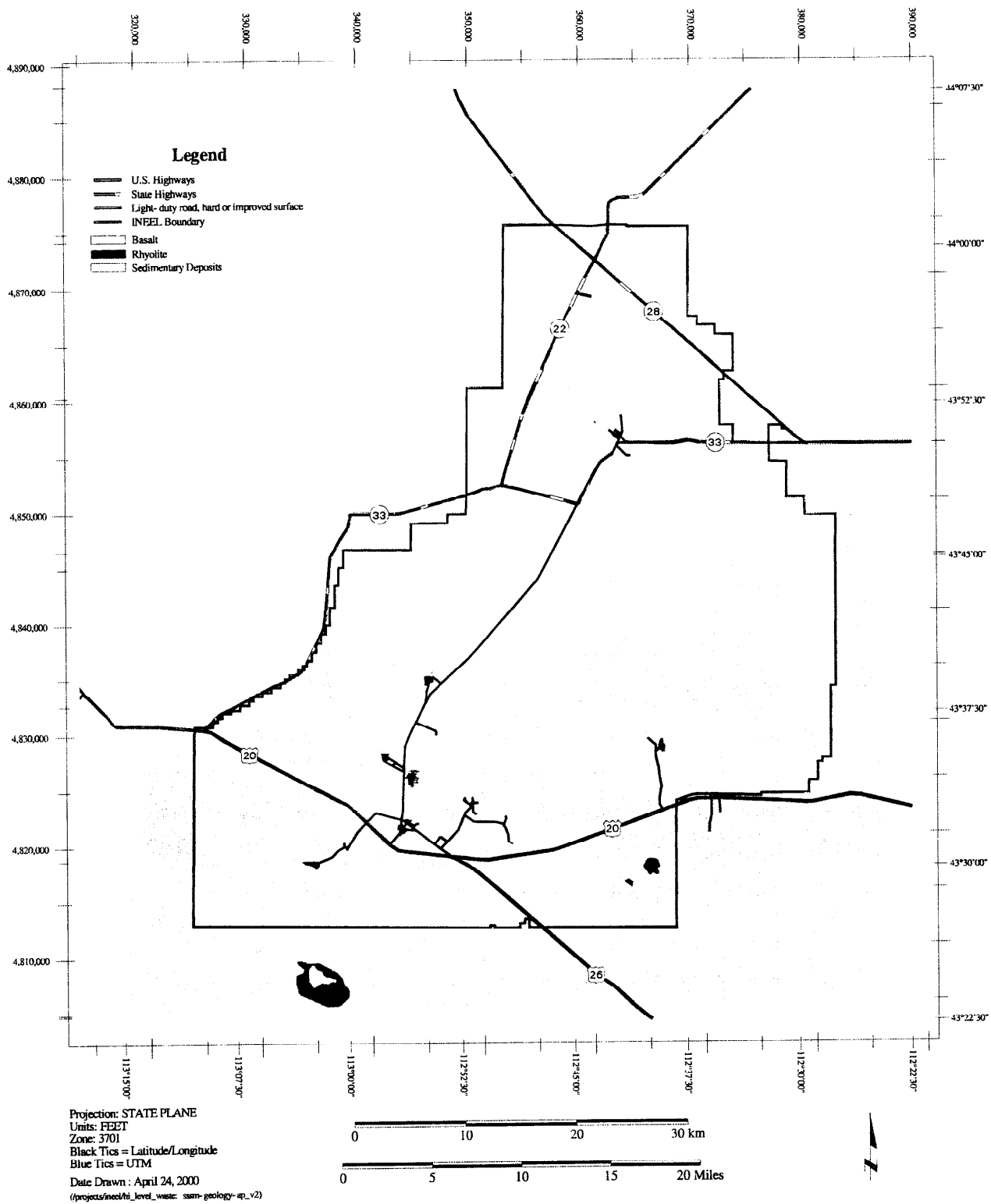
Figure B-10. Areas dominated by rock outcrops and sediments on the INEEL.
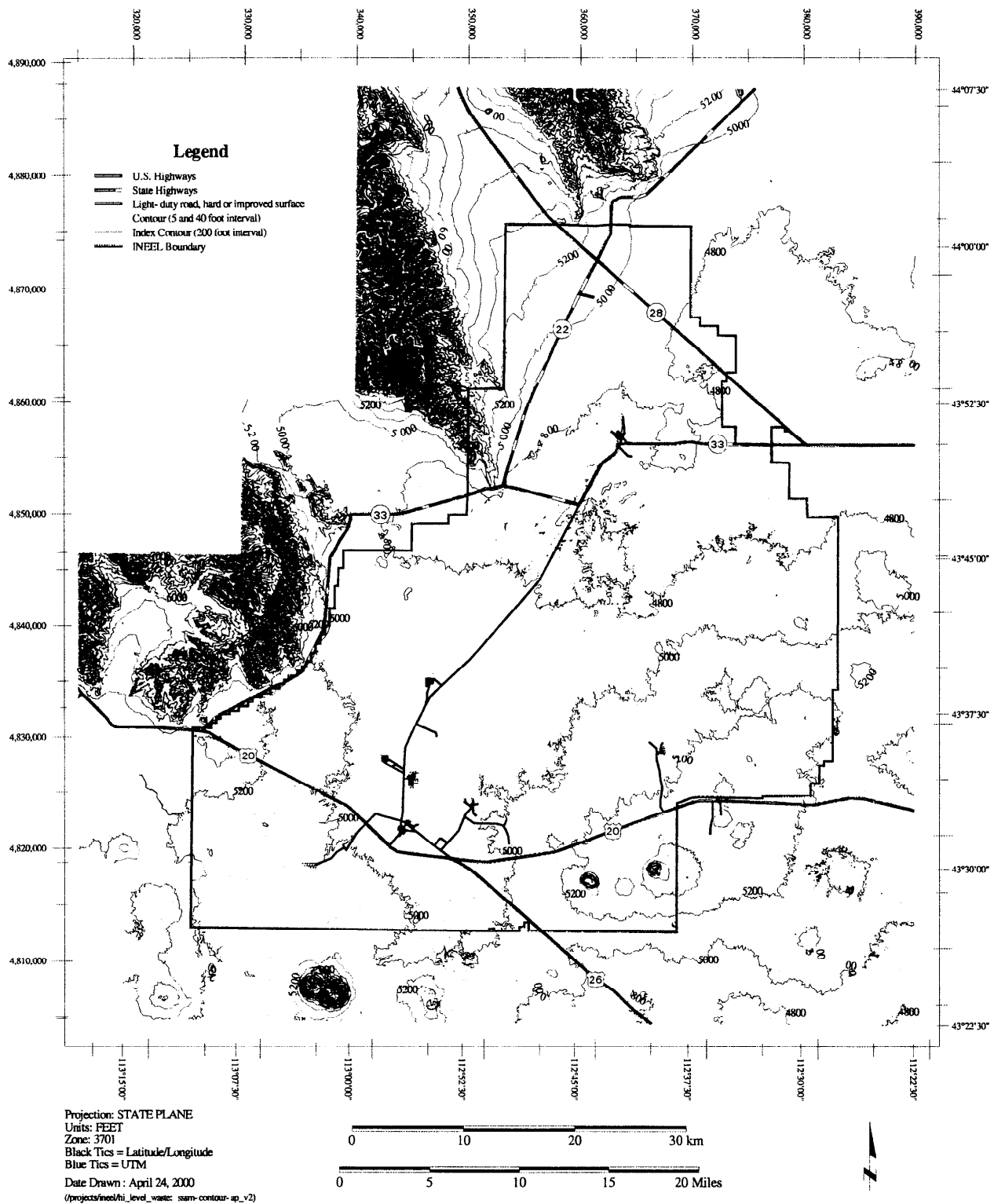
Figure B-11. INEEL topographical contours.

The largest recorded earthquake in the vicinity of the INEEL was the 1983 Borah Peak earthquake, magnitude 7.3, on the middle portion of the Lost River Fault near Mackay and Challis, about 80 km from INEEL facilities. No damage occurred at INEEL facilities as a result of this earthquake (Jackson 1985; Jackson and Boatright 1987). Another large earthquake, the Hebgen Lake (M 7.5) earthquake, occurred on the Yellowstone Plateau in 1959, about 200 km from INEEL facilities, producing no damage at the INEEL. Both of these earthquakes occurred within a parabolic zone of historic recorded seismicity and young faults that passed through the Yellowstone Plateau and flanks the ESRP (see Figure B-11) (Anders et al. 1989). Earthquake monitoring by the INEEL seismic network and other networks show that the ESRP and adjacent parts of the nearby mountain ranges lie in a zone of very low seismicity inside the seismically active parabolic zone (Jackson et al. 1993). During the ~30 years of earthquake monitoring by the INEEL seismic network, only a few microearthquakes (M less than 2) have occurred on or near the INEEL (Jackson et al. 1993).

Studies of the southern ends of the Lost River and Lemhi faults near Arco and Howe show that earthquakes as large as the Borah Peak earthquake occurred there most recently about 20,000 years ago (Woodward-Clyde Consultants 1992; Woodward-Clyde Federal Services 1995). The current probabilistic seismic hazard assessment for INEEL facilities (Woodward-Clyde Federal Services 1996) uses the results of the fault studies and other recent geologic and seismologic investigations. Results of the seismic hazard assessment are incorporated into INEEL seismic design criteria.

The vent areas for basalt volcanism are not randomly distributed on the ESRP, but are concentrated in elongate northwest-trending volcanic rift zones and along the Axial Volcanic Zone (see Figure B-12). Basalt volcanism is the most significant volcanic hazard for INEEL facilities, but the annual probability of inundation for any INEEL facility is about 10^{-6} or less (Hackett et al. 2000). The probability drops rapidly with distance from volcanic rift zones (see Figure B-13). The hazard due to seismicity associated with volcanism is addressed in the INEEL probabilistic seismic hazard assessment (Woodward-Clyde Federal Services 1996) and discussed in detail in Smith et al. (1996).
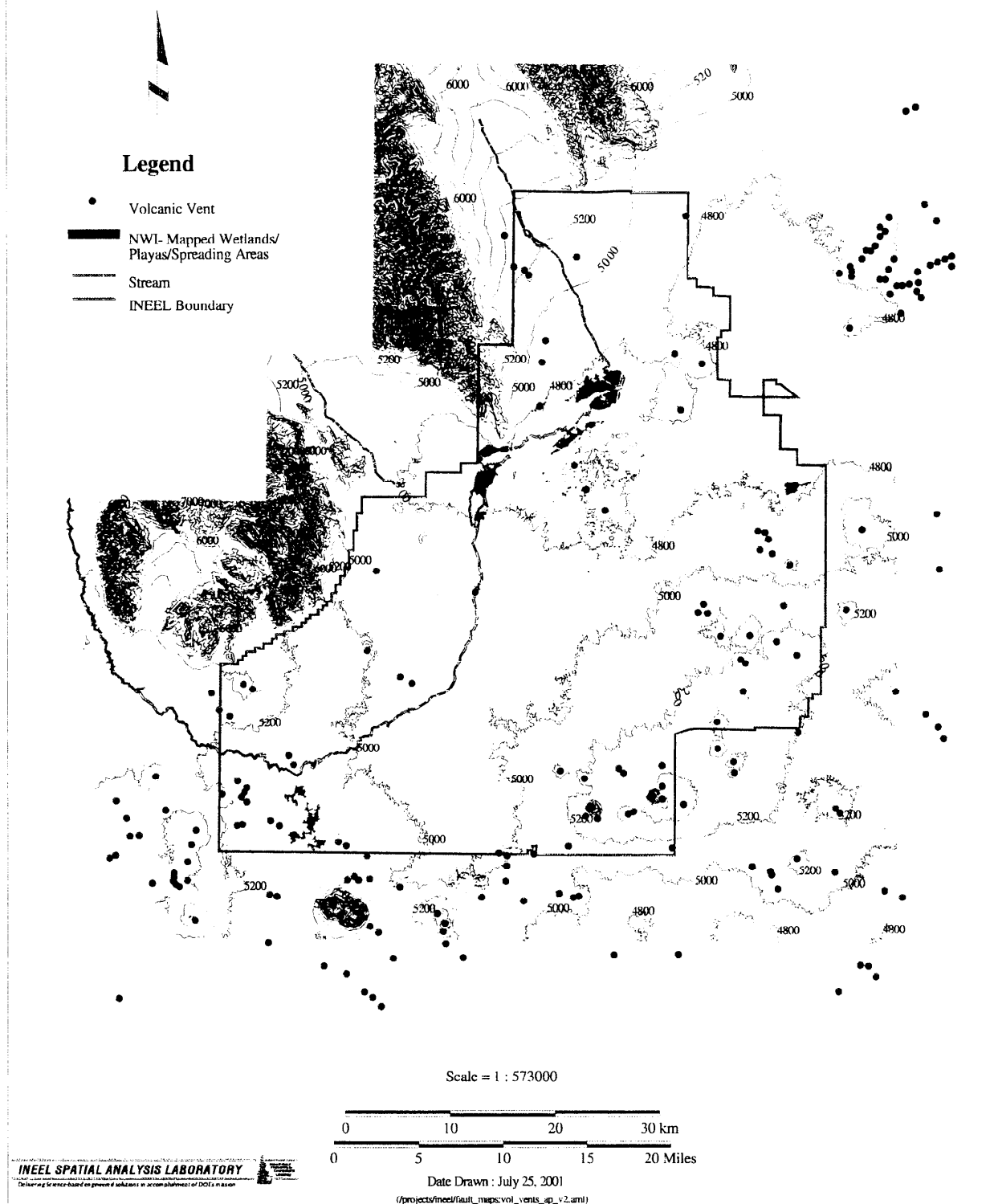
B-4.4 Soils

The INEEL soils are derived from silicic volcanic and Paleozoic sedimentary rocks from nearby mountains. The soils in the northern portion of the INEEL are generally composed of fine-grained lacustrine and eolian (wind carried) deposits of unconsolidated clay, silt, and sand. Typically, soils in the southern INEEL are shallow, consisting of fine-grained eolian soil deposits with some fluvial gravels and gravelly sands (EG&G 1988). Across the site, measured surficial soil thicknesses range from zero at basalt outcroppings that dot the landscape (around PBF, for example) to 95 m (313 ft) near the Big Lost River Sinks southwest of TAN (Anderson et al. 1996b).
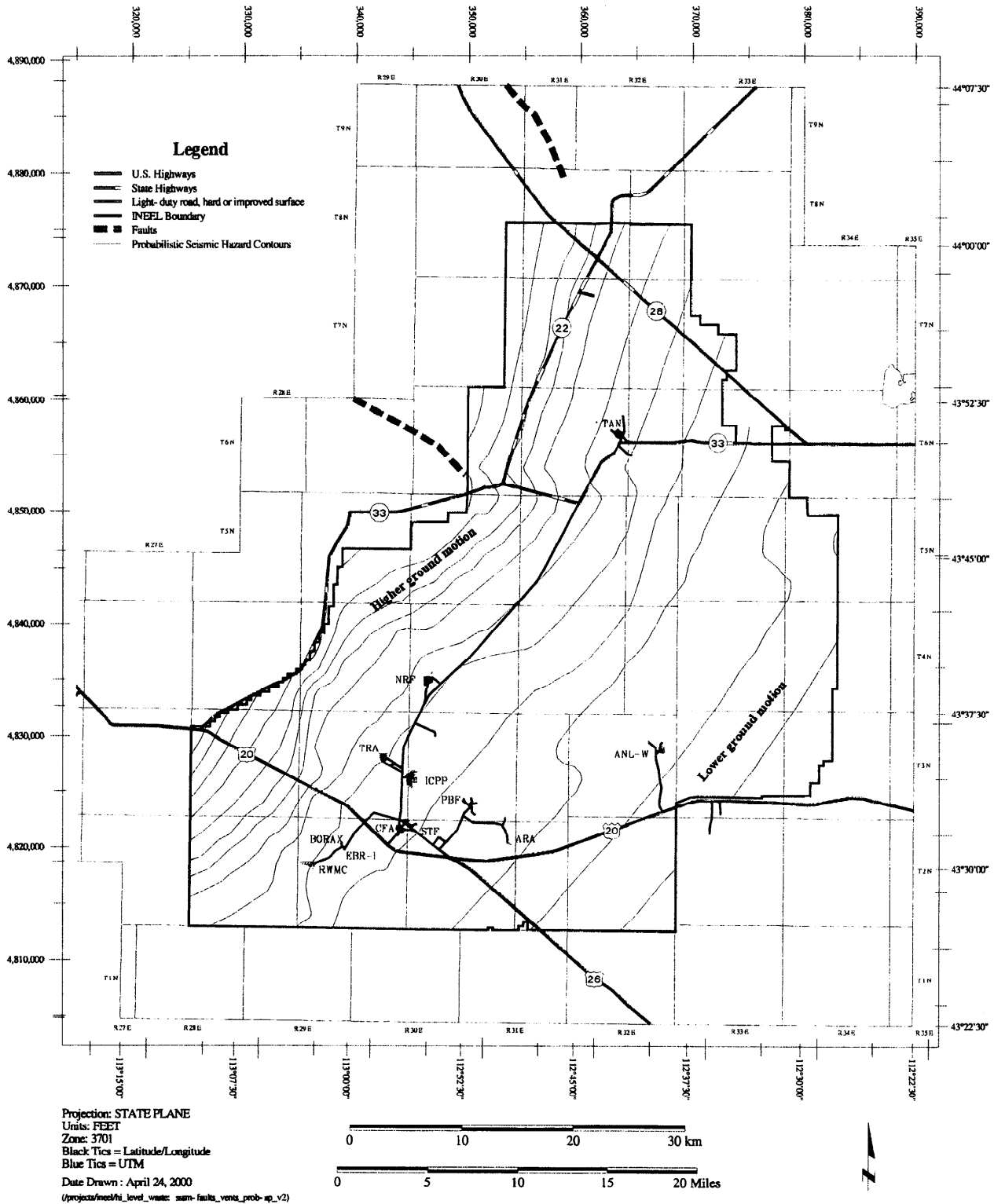
Four basic soilscapes exist at the INEEL: (1) wind-blown sediments (eolian) over lava flows, (2) river-transported sediments deposited on alluvial plains, (3) fine-grained sediments eroded into lake or playa basins (lacustrine), and (4) colluvial sediments (loose deposits of rock debris collected at the slope base) originating from bordering mountains. Figure B-14 depicts the soils typically found on the INEEL. This map resulted from an Order 4 or 5 soil survey, as defined by the U. S. Natural Resources Conservation Service, and conveys only broad-scale landscape associations. Complete descriptions of mapping units are provided in Olson, Jeppesen, and Lee (1995). The alluvial deposits follow the courses of the modern Big Lost River and Birch Creek. The playa soils are located in the north-central part of the INEEL site. The colluvial sediments are located along the western edge of the Site. Silt- and sand-covered lava plains occupy the rest of the INEEL landscape.
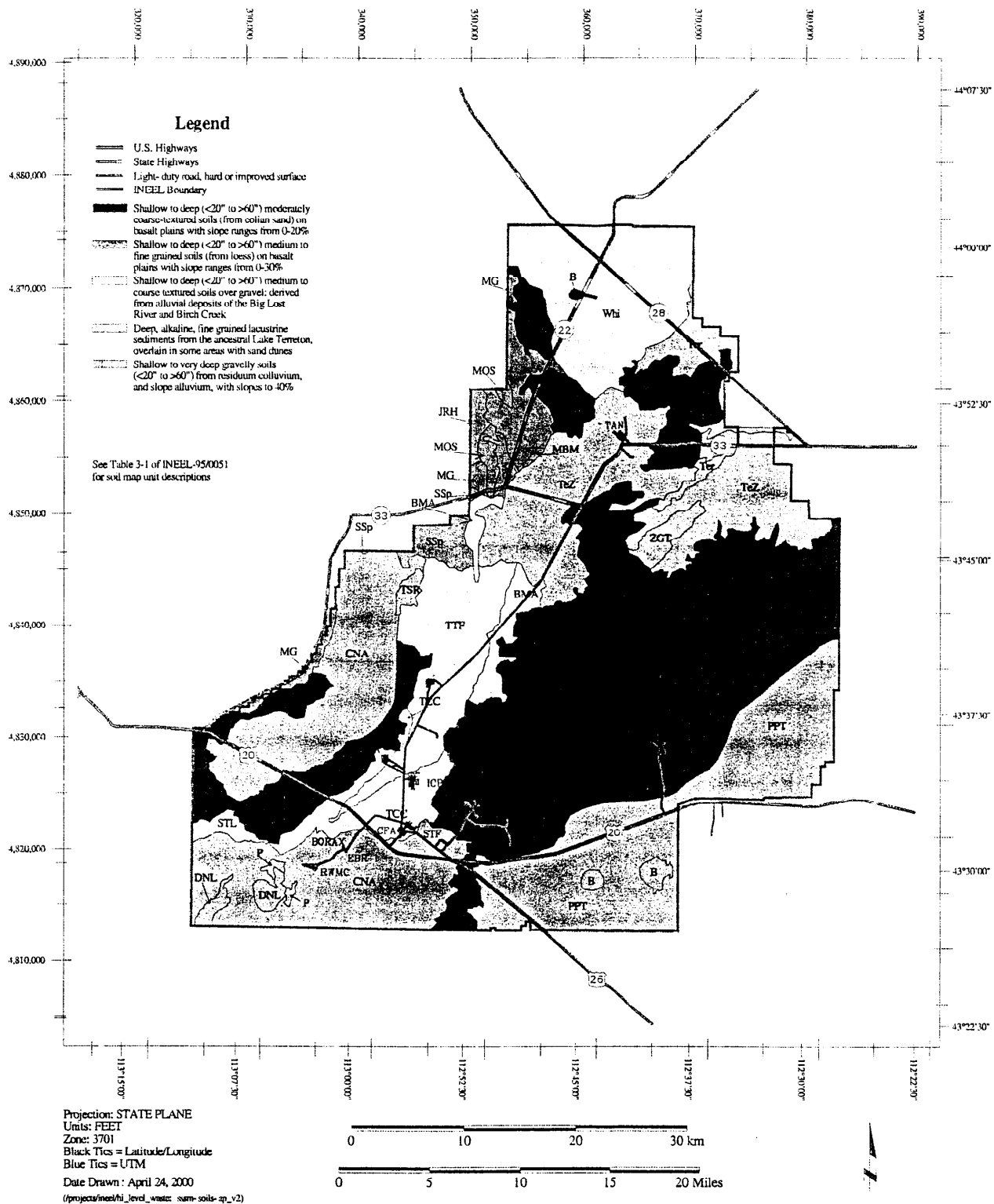
Figure B-12. Idaho National Engineering and Environmental Laboratory Volcanic Vents and Topography.

Figure B-13. General direction of increasing probabilistic ground motion across the INEEL.

Legend

U.S. Highways
State Highways
Light- duty road, hard or improved surface
INEEL Boundary

Shallow to deep (<20" to >60") moderately coarse-textured soils (from eolian sand) on basalt plains with slope ranges from 0-20%

Shallow to deep (<20" to >60") medium to fine grained soils (from loess) on basalt plains with slope ranges from 0-30%

Shallow to deep (<20" to >60") medium to course textured soils over gravel: derived from alluvial deposits of the Big Lost River and Birch Creek

Deep, alkaline, fine grained lacustrine sediments from the ancestral Lake Terreton, overlain in some areas with sand dunes

Shallow to very deep gravelly soils (<20" to >60") from residuum colluvium, and slope alluvium, with slopes to 40%

See Table 3-1 of INEEL-95/0051 for soil map unit descriptions

Projection: STATE PLANE
Units: FEET
Zone: 3701
Black Tics = Latitude/Longitude
Blue Tics = UTM
Date Drawn : April 24, 2000
(/projects/ineel/hi_level_waste: susm-soils-ap_v2)

0   10   20   30 km

0   5   10   15   20 Miles

Figure B-14. INEEL surface soils (Olson, Jeppesen, and Lee 1995).